A Study of Technical Surveillance Countermeasures Requirements

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A STUDY OF TECHNICAL SURVEILLANCE COUNTERMEASURES REQUIREMENTS

January 1959

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PREFACE

Pursuant to the National Security Council Action #1774, approved by the President on 23 August 1957, The National Security Council Special Committee on Technical Surveillance Countermeasures was requested to intensify its efforts to develop a coordinated research program to insure development of practicable detection devices adequate to meet the growing threat of hostile technical devices.

As a result of a unanimous decision on the part of representatives of the Army, The State Department, The National Security Agency (NSA), The Federal Bureau of Investigation (FBI), The Central Intelligence Agency (CIA), The Department of Defense, The Navy Department, The Marine Corps, and The Air Force, on 5 March 1958, the responsibility for conducting a preliminary study of the problem was vested in a single agency (CIA).

On 11 June 1958 a contract was let by the CIA with [redacted] 25X1 25X1 to chairman a working group of consultants. The group, either as a result of their own knowledge or through contacts (governmental, industrial, etc.), were engaged to determine the extent, nature, and scope of the threat to the nation as a result of our present inadequacies in surveillance countermeasures equipment.

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This study was initiated with the principal objectives of recognizing and recommending a research and development program aimed at providing <u>practical</u> and <u>effective</u> countermeasures where existing countermeasures equipment is inadequate.

To accomplish this end, the following investigations were proposed by the study group:

a. offensive devices and techniques known to have been used or presently being used by the opposition would be categorized,

b. offensive devices and techniques used in our own interest in the past or at present would be categorized,

c. offensive devices or techniques which have not been used or pursued by the opposition or ourselves but which are scientifically realistic and, accordingly, represent a threat would be evaluated,

d. the extent to which our knowledge or available counter-measures offset the threat of the opposition would be determined.

Although emphasis was to be primarily on devices and techniques associated with [redacted] and countermeasures, due attention was to be given to other related security considerations such as landscapes, building structures, personnel, etc. 25X1

Data in the report which follows was compiled over a period of approximately six months, and it represents the efforts of the group whose names and affiliations are set forth at the end of this preface.

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At this time, they would like to express their sincere appreciation to the contributors from the many government, industrial, and educational operations who gave freely of their time and knowledge to make this study as complete and effective as you may be willing to concede as an interested and concerned reader.

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ABSTRACT

This study points out quite emphatically and appropriately that as individuals we talk too much and too often about classified subjects, particularly in improper places, and that we are careless in our handling of classified documents and information in general.

True security is acknowledged to be attainable only with complete isolation from people and information. Limited isolation, or none whatsoever, makes our position vulnerable in proportion to our laxity regarding good and tested security procedures, our personal complacency and, to a lesser extent, our inadequacies in technical aids and supporting countermeasures equipment.

Equipment presently available to a surveillance or countermeasures team, although it is already bulky, heavy, and inadequate, can only be expected to increase in bulk if unassisted technical protection is to be the immediate goal. This is particularly true unless first and primary attention is given to indoctrinating personnel in accepted security procedures, to selecting facilities with security in mind, and to limiting the storage of, the accessibility to, and the transfer of information on a strict "need to know" basis.

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If controls with "teeth" in them cannot be administered by responsible personnel, then the current threats due to inadequacies in technical aids probably cannot be significantly minimized in the foreseeable future. Technical aids should be looked upon as supporting and supplementary protection and not as a primary defense.

With this approach to the philosophy of security, supporting countermeasures can be developed, hopefully with the weight and bulk specifications approaching the desires of security and surveillance teams. For the present, however, these features will have to be forfeited for protection against the threat of our primary inadequacies.

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SUMMARY OF PRINCIPAL CONCLUSIONS

As it was pointed out in the Preface of this report, this study was initiated with the principal objectives of recognizing the need for and recommending a research and development program aimed at providing practical and effective countermeasures where existing countermeasures equipment is inadequate. Due attention is given to the fact that certain physical and scientific situations may exist to restrict the effectiveness of specific positive surveillance techniques and that appropriate precautionary and preliminary security measures may be taken to reduce the magnitude of the threat. It may be rather generally stated that when a high degree of security or secrecy is associated with a positive surveillance technique, the operational problems associated with it increase probably well out of proportion to the probability that the technique will be employed. Typical of the problems that are encountered are those relating to the selection of appropriate sites for the installation. Specific instances of such installations will be discussed in detail in order to justify the low probability that has been placed on the development of countermeasures equipment to negate their effectiveness.

The following summary of conclusions is accordingly presented.

An effective and coordinated development program should be initiated and carried forth, realizing that expenditures for the first few years, at least, will represent [redacted] 25X1

25X1 [redacted] The program must be systematic, complete, and an "all-out" effort intent on promptly, effectively, and practically providing the best answers to our shortcomings. The anticipated cost appears to be reasonable in view of the intelligence value and the protection that will be derived from it. It should simultaneously be considered as beneficial to all interested parties and representatives of the total dollars being spent by all of the interested parties at the present time but in an uncoordinated fashion.

Being fully aware of the improbability of providing 100% effective detection capability throughout the entire acoustical and electromagnetic spectrum for a reasonable length of time and in a finite period of time and that true security comes only with complete isolation, best effort and the necessary dollars should be directed:

1) to indoctrinate personnel so that they appreciate the seriousness of the problems associated with the need for good security, so that they are aware of the positive surveillance measures and the available countermeasures with their shortcomings, so that they are aware of their personal responsibilities

with regard to security and the penalties associated with neglecting to take adequate precautionary measures;

2) to establish adequate security controls to assist and provide checks on personnel and their activities;

3) to select controlled and secure areas with due concern for the problems that may be encountered both from a technical and a non-technical standpoint;

4) to permit technically qualified personnel to be hired and properly supported with an understanding administration as well as with adequate technical equipment and to be available to get the best out of the technical aids to be provided;

5) to provide, in lieu of or in addition to the "bag of tricks" presently being used, tools and equipments adequate to meet the threat of Soviet penetrations which may result from our overall security program.

What then are the principal technical items that should receive priority attention in a proposed development program? The following are arranged in their anticipated order of importance:

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It should not be implied that the recommendations, as presented in this summary, cover all of the equipments which are appropriate to a complete countermeasures program. They are presented because they reflect the nature of our most significant shortcomings from an equipment standpoint. The report which follows hopefully substantiates these recommendations and places acquired facts, and conclusions drawn therefrom, in their proper perspective.

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INTRODUCTION

There are many ways in which a report or a program of this type may be approached. Alternate programs may yield adequate answers to the problems that exist. The approach adopted, however, is designed with the intent of providing a thorough understanding of all of the existing and potential countermeasures. The report is developed in three phases: "A Pattern for Analysis", "Considerations of Positive Surveillance Measures and Surveillance Countermeasures", and "A Proposed Development Program". Following the two initial phases to determine the adequacy of our countermeasure capabilities, detailed conclusions and recommendations are presented pursuant to fulfilling the objectives of the study which were tabulated in the Preface.

The last two sections of the text to follow may be read and comprehended without first reviewing or reading the first section, "Patterns for Analysis," but it is believed that continuity and understanding can best be acquired by appraising the scope of this study in the order in which it is presented.

PATTERNS FOR ANALYSIS

1. 1. 0 The Systems Concept

The attempt herein is to provide a pattern of analysis by developing a systematic arrangement of the general concepts which will lead to an enlightened understanding of the problems involved. The systems concept is fundamental to the discussion. Although the material may be redundant in some aspects and superfluous to others, it is believed to be the necessary first step in establishing a system of agreed upon conventions which will allow generalized discussions in subsequent phases.

1. 1. 1 Systems and Society

It is generally agreed that all technical or scientific activity may be assigned to any one or a combination of the three subjects denoted as:

(1) energy,

(2) materials,

(3) information.

Progress in technical activities has produced an involved pattern of organized systems of men, machines, and environment designed to handle and process energy, materials, and information.

These organized technical systems of energy, materials, and information operate within a framework of human values defined by ethical, moral, religious, and cultural considerations together with their legal and economic consequences. Modern civilized society results from the very complicated and dynamic array of forces produced when these technical systems are forced into the framework of human values.

This dynamic array of forces is dislocated and brought to serious imbalance by the creation of new technological systems or through changes in the patterns of human values. There is probably no way to avoid completely this dislocation of forces and its resulting impact upon human values. The conflict between the Soviets and Soviet dominated countries and ourselves and our allies, between different economic and political systems, makes technological advance a necessity.

This places a twin burden of responsibility upon the shoulders of engineers and scientists. They must creatively exploit their knowledge of energy, materials, and information to improve existing, and design new, organized systems of men, machines, and environment while protecting and enhancing their human values.

This brief introduction is an attempt to show that the general

problems associated with this study have basic interests in two fundamental areas:

(1) technical systems

(2) human values.

While considerations of technical systems provide the central theme of the study, it is recognized that any system of human values always imposes design constraints upon the technical aspects of the problem. Hence, in the design of positive surveillance systems and particularly in our attempts to provide adequate countermeasures against Soviet measures, differences between our human values and those of the Soviets must be evaluated and realistically considered.

1.1.2 Surveillance Interests

The surveillance interest in the systems concept is derived from both technical systems and the systems of human values which impose constraints upon the properties of the technical system.

The technical entity being considered at any given moment may be a microphone installation, a telephone installation, or a wireless installation, to name only a few. Whatever examples are chosen, it is always true that they are a fragmentary part of some larger entity, or technical system.

1.1.3 Basic Functions Present in Systems

While we recognize the existence of many systems of values, our concern herein is primarily with technological systems and their description.

A system in the sense which will bear significance in this study is defined as any complete instrumentality which performs a specified task. The degree of complexity is not essential to the definition. Very simple systems, such as a contact microphone, an amplifier, and a listener with headphones, or very complicated systems, such as miniature transmitters remotely actuated by a listener at a receiving post using an actuating transmitter, selective receiver, and recording equipment, are both characterized by certain fundamental functions. The existence of these interconnected functions distinguishes a system from a mere collection of devices and things. These functions are identified and defined in this paragraph.

Technological systems handle or process energy, materials, or information, either singly or in all possible combinations. All systems possess a common series of necessary and intrinsic functions. There are six basic functions which may be identified as follows:

(1) transfer functions

(2) operational functions

(3) conversion functions

(4) source functions

(5) acceptor functions

(6) interconnection functions.

For ease of representation on paper, systems are conventionally represented in block diagram form where each block represents a basic function of the system. Thus, the functions listed lead to the specification of the basic building blocks of all systems. These are defined and described in the few paragraphs that follow.

Transfer Element

A transfer element represents the functional relationship between a single input quantity, X_1, at one point in space or time and a single output quantity, X_2, at a different point in space or time. The input is the independent variable and the ratio of output to input is defined as the transfer function Y_{12}. That is

$$Y_{12} = \text{transfer function} = \frac{X_2}{X_1} .$$

The transfer function defines the alteration of the input as it is transferred in space or time by the transfer medium denoted by (T). The input and output quantities must be of the same kind so that (Y_{12}) is dimensionless. These transfer elements serve to transfer energy,

materials, or information from one point in space or time to another point. Typical examples include transmission lines, conveyor belts, and "memory" or storage elements in computers.

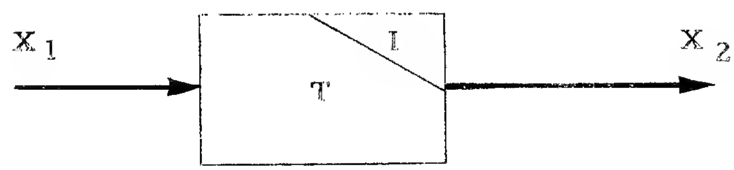

Figure (1.1) - The Transfer Element

The symbols in the corner triangles of the block diagram shown may denote the following being transferred:

I = information

W = energy

M = materials .

(T) represents a transfer function relating the quantities X_1 and X_2 .

Operational Element

An operational element represents the functional relationship between single or multiple input quantities, X_1 , X_2 , X_3 . . . . X_n , and single or multiple output quantities, X_a , X_b , X_c . . . . X_n . The input quantities are the independent variables and the output is a function of some combination of input quantities. That is

$$X_a = f_a\ (X_1,\ X_2,\ X_3 \ldots .\ X_n)$$

$$X_b = f_b\ (X_1,\ X_2,\ X_3 \ldots .\ X_n)$$

$$X_c = f_c\ (X_1,\ X_2,\ X_3 \ldots .\ X_n)$$

$$\vdots$$

$$X_m = f_m\ (X_1,\ X_2,\ X_3 \ldots .\ X_n)\ .$$

or if presented in block form

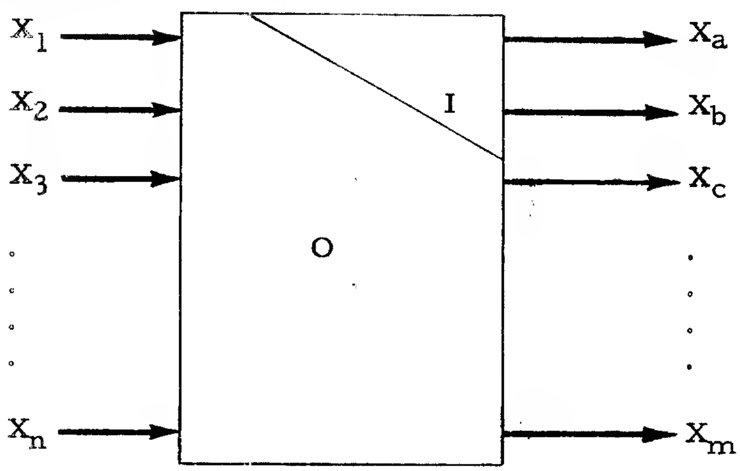

Figure (1. 2) -- The Operational Element

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Conversion Element

A conversion element represents the functional relationship between an input in one energy or material category and an output in another energy or material category. There are four such functional relationships:

(1) energy (form 1) converted to energy (form 2)

(2) material (form 1) converted to material (form 2)

(3) energy converted to material

(4) material converted to energy.

Because information is always carried by either energy or material, there are no converters of information. When such a condition apparently exists, it will always be the result of an energy or material conversion. Examples of conversion elements include 25X1

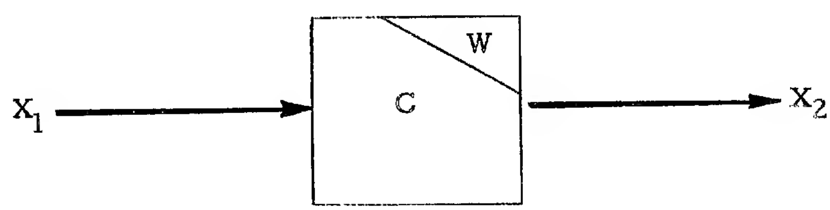

Figure (1.3) - The Conversion Element

Source Element

This element denotes the source or point of origin of energy, material, or information in any system.

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Acceptor Element

This element is the recipient or acceptor, and occasionally the consumer, of information, energy, or material.

Interconnecting Path Elements

In the block diagram of a system, referred to previously and discussed in more detail in the next section, direct, or primary, connections between the five basic building blocks are denoted by solid lines with arrows pointing in the direction of energy, material, or information flow.

Indirect, or secondary, connections between the five basic building blocks are denoted by dotted lines with arrow heads showing the direction of flow.

Several examples of simple systems are presented in the next section. Each system is described in terms of the functional elements defined in this section. These serve to illustrate the use of these functional elements and their composition into a system block diagram. Such block diagrams will be invaluable later when we approach specific surveillance systems and the countermeasures associated with them.

1.1.4 Functional Block Diagram Description of Systems

The functional elements defined in section (1.1.3) can be used to describe any physical system of any degree of complexity

and to any degree of detail desired. This is illustrated for a few very simple systems in this section.

One of the simplest of all systems consists of a source and receptor connected by a transfer element. This might represent a magnetic recording head, a magnetic tape, and a play-back head. The source, the recording head, deposits energy onto magnetic tape which, in turn, acts as the transfer element and ultimately the energy is removed from the tape at a different point in space and/or time by the pick-up head. This provides an adequate description of the transfer system. See the simple block diagram provided in Figure (1.4).

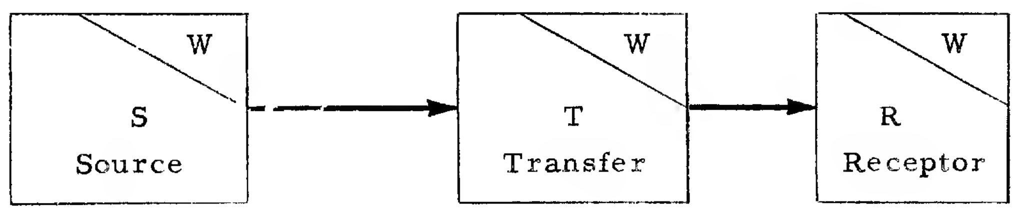

Figure (1.4) - Simplest System Block Diagram

However, energy is required to drive the magnetic tape and activate the heads, etc. and some kind of simple control, or information, system is required at the heads and tape to direct the recording and play-back sequences. Thus, a complete system description would

require a block diagram representation of energy and information functions. Because these are secondary to the primary problem of recording energy, they are connected into the system by dotted lines, whereas the basic functions are interconnected by solid lines. When the system is re-drawn to include the secondary energy systems, but neglecting the control or information aspect, it appears as shown in Figure (1.5).

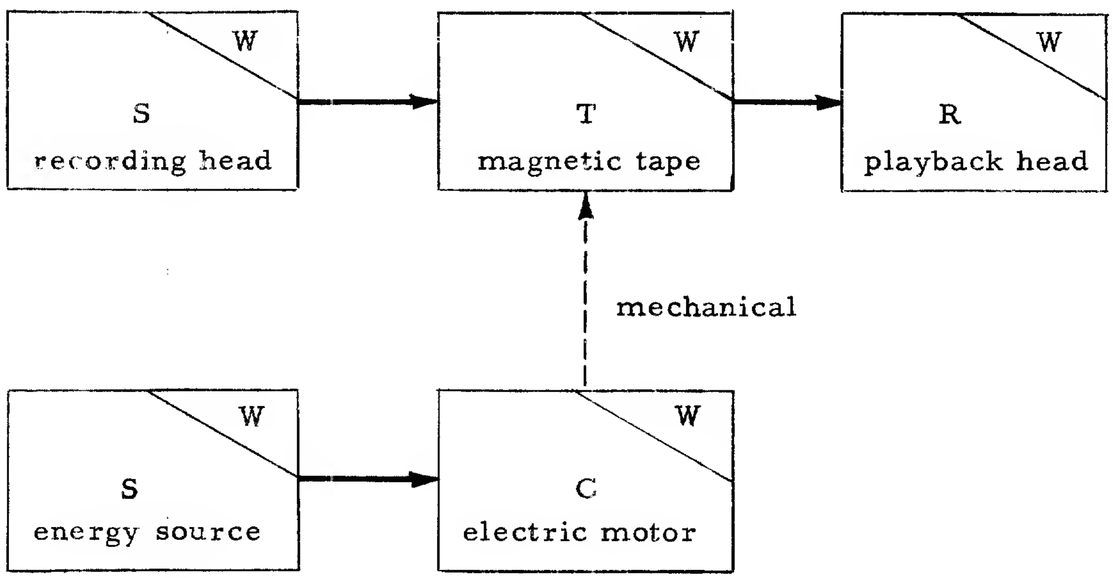

Figure (1.5) - More detailed system block diagram

A record player is another comparatively simple system, but one incorporating some slightly different system concepts. In its purest form, this is an information system. Information has been stored in the grooves of the record. Thus, the record is a transfer element because it transfers information from one point in time or

space to another. It is important to note that information is stored here in material form. It is a characteristic of all information systems that information has no independent existence; it is always present in conjunction with either energy or material. Thus, we very commonly speak of information as being carried by energy or material.

While the record is a transfer element in the general sense of being a connection between the recording artist or speaker, being surveilled, and some listener, it serves as the information source in the very restricted system of the record player. The information on the record is extracted by placing it on a rotating, motor driven turntable in contact with a stylus. This converts the irregularities in the grooves into mechanical vibrations. This is converted to electrical energy by a crystal. After the multiplication of electrical energy through the operation element, or electronic amplifier, the information is converted into an acoustical form in the loudspeaker and this is transferred by the air to the listener. The system then appears as shown in Figure (1.6). Note that an electrical energy source has been added to supply the electronic amplifier with power. Also note that this system involves material, energy, and information. The three are nearly always present in every system that will concern us in this study.

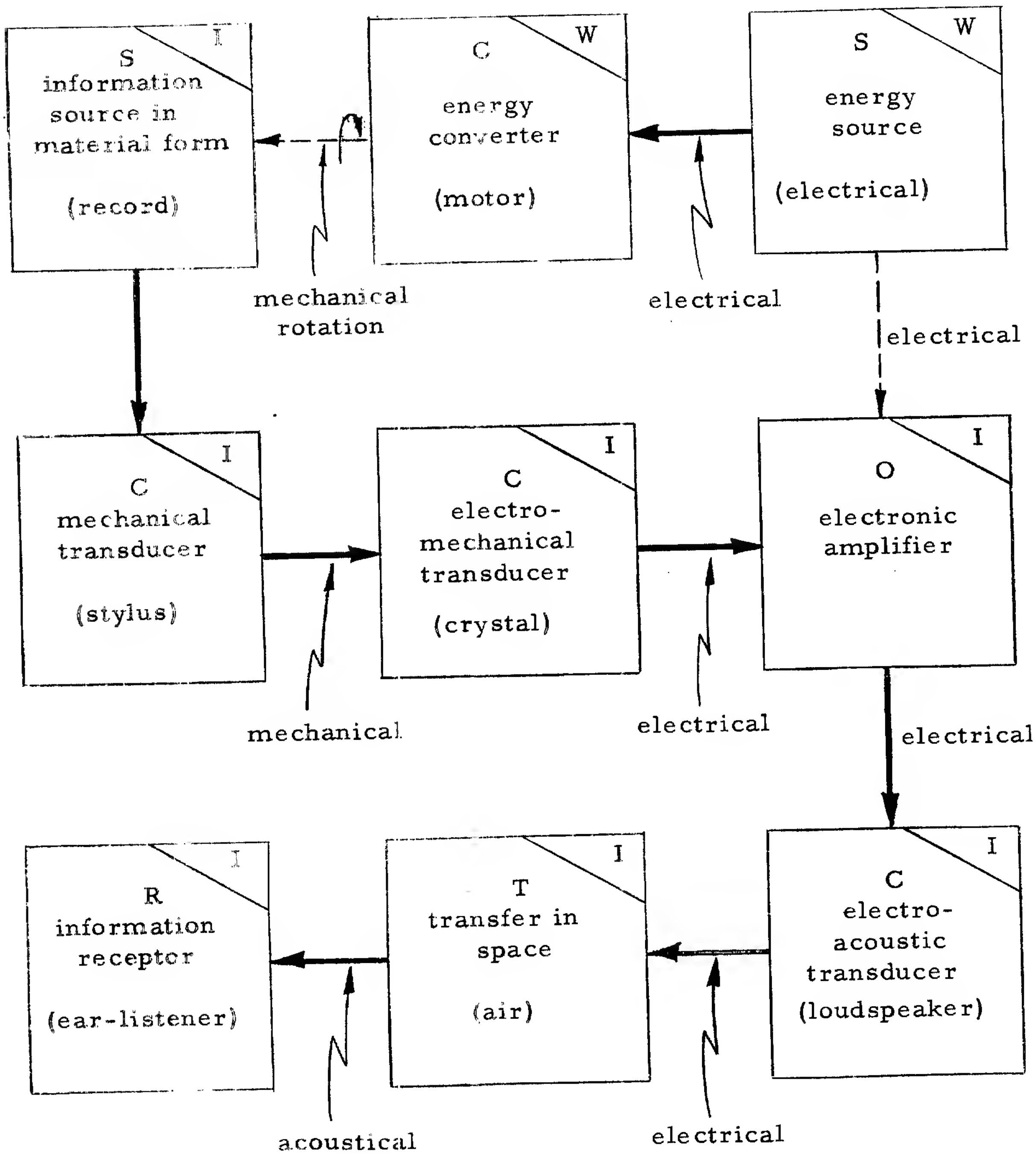

Figure (1. 6)

System Block Diagram of the Functions in a Record Player

The ordinary typewriter, which may be of considerable intelligence value, provides some excellent examples of the operational element in system block diagrams. A typewriter is a very complicated system and we will describe only a few of its essential features. The 44 keys on a standard keyboard, together with the space bar, back space, shift or cap keys, margin release, tab key, and line space lever are all information and energy inputs to the machine. The paper rolled on the platen is the receptor, while the typist is the source. A simple system description of a typewriter appears as shown in Figure (1. 7). The description in Figure (1. 7) omits many important details required in a complete description, however. There are many other sources of instructions to operational elements together with the mechanical energy system required to operate the device.

These illustrations have been chosen because of their commonplace character. Each, in its own right, possesses the properties of a small system. However, each can be, and generally is, a fragmentary part of some larger system.

The point of the discussion in this section is simply that the same technique of description is used for all systems, without regard to system size, complexity, or desired detail of description. While it may seem that the case is overstated, the use of functional

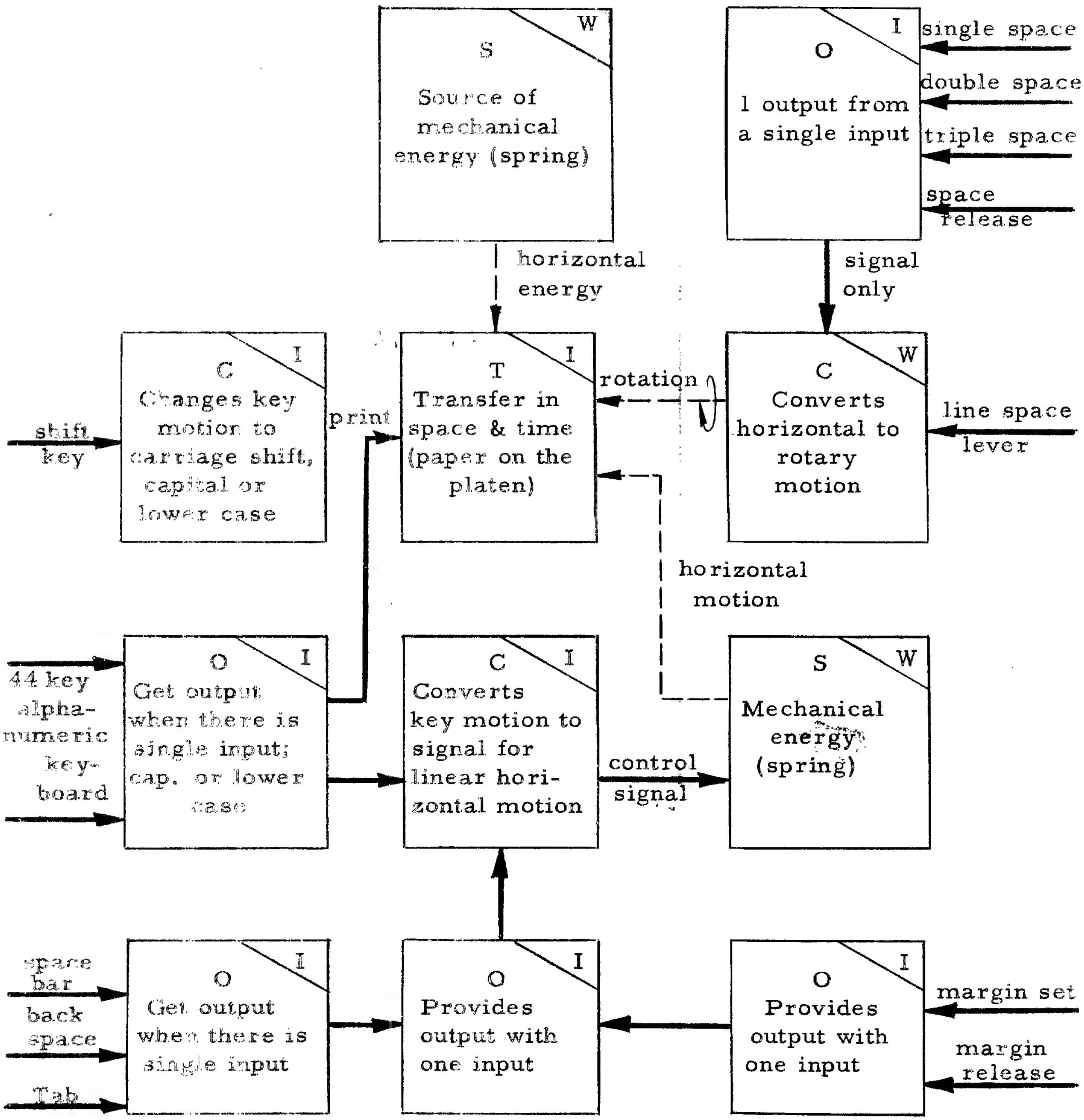

Figure (1. 7) - Partial System Description of a Typewriter

block diagrams is the first step toward a systematic understanding of system operations and system designs such as we will be analyzing subsequently.

1.2.0 Information Systems

From the very brief discussion in section (1.1.4) it is clear that nearly any system, except a very rudimentary and primitive one, invariably involved energy, information, and materials, although only one of the three may be of primary concern. This is particularly true of information systems because information has no independent existence.

When information is transferred from one point to another in space, the transfer is most often associated with electrical energy. On occasions, it may be transferred optically, acoustically, materially, etc.

Here we describe the fundamental concepts involved in the theory of information. The discussion commences with the definition of generalized information systems, proceeds to an analysis of human information systems, and concludes with a description of machine systems.

1.2.1 Fundamentals of Information Systems

This section is a comparatively detailed analysis of the

fundamental aspects associated with information systems.

An examination of the subject matter associated with information systems suggests that there are five "fundamental principles" which are distinct and identifiable. The study of information systems proceeds from five "levels" of principles as follows (see Figure 2. 1):

(1) physical principles

(2) circuit theory principles

(3) modulation and coding principles

(4) machine sub-system principles

(5) system engineering principles.

This makes the presentation of information systems multi-level in character as shown in Figure (2. 2). New ideas and principles are introduced at all levels so that a presentation is not wholly sequential. Rather, the system has a core which is fed and drained by ancillary sub-systems.

1.2.2 Types of Information Systems

In a very broad sense, there are only two fundamentally different types of information systems:

(1) Information transfer, or communication systems, transfer information in space, or time, or both. Such

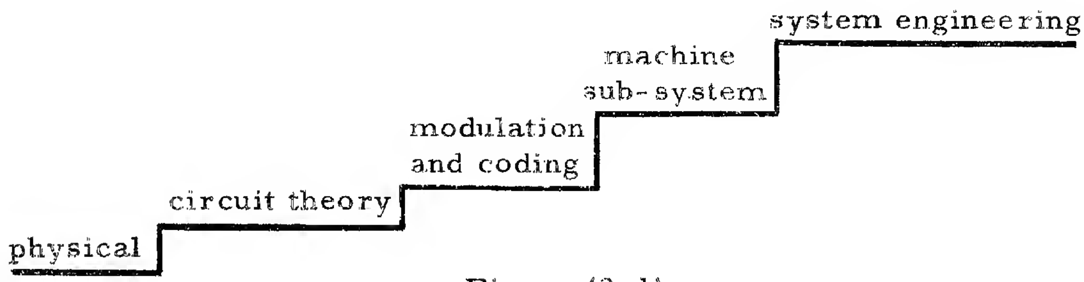

Figure (2. 1)

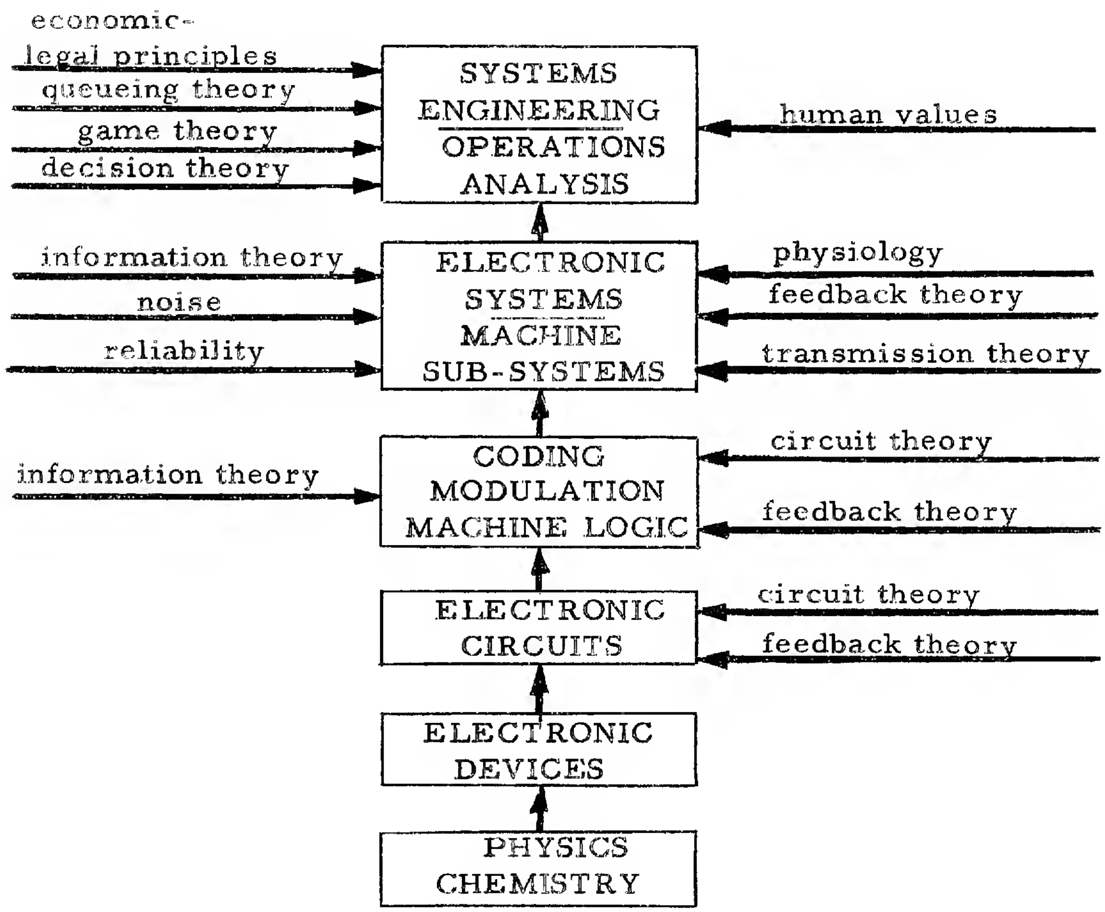

Figure (2. 2)
Information systems showing initial dependence upon physical fundamentals followed by the introduction of engineering fundamentals at successive levels

systems are characterized by single or multiple information channels which are independent of one another.

(2) Information operation, or processing, systems perform operational functions upon information. Such systems are characterized by multiple information channels which are interdependent.

All modern information systems, when considered in their entirety, usually involve both communication and processing.

The communication system is concerned with the transfer of information in space or time. There are only two classes of such systems, and only two sub-types of each class, as follows:

(1) Communication from man-to-man.

(a) from one point in space to another

(b) from one point in time to another

(2) Communication from machine-to-machine

(a) from one point in space to another

(b) from one point in time to another

Because information always exists in association with material or energy, it is a natural consequence of physical laws that information transfer from one point in space to another is always accompanied by a corresponding transfer in time.

Four other problem areas, apparently related to the foregoing, are often considered to be communication. These are identified as communication from

(1) man-to-machine in space or time

(2) machine-to-man in space or time

(3) one man-to-another man of different logic process

(4) one machine-to-another machine of different logic process

In these four cases, the basic logic processes must be altered. Each is characteristically an operational or processing function, rather than communication or transfer. This is one class of information processing systems.

In all information processing systems operations are performed upon information to

(1) develop new information, or to

(2) develop new interpretations of existing information.

For example, the numbers three and two represent information that can be communicated in space or time. However, the operations required to express them in binary form or to get their sum, difference, quotient, or product constitute various aspects of information processing.

To sum up, information processing systems are characterized by three different functions:

(1) mathematical operations

(2) alterations in logic process

(3) decision-making

The purpose of these three operations is to produce new or additional information or new interpretations of existing information.

1.2.3. Basic Properties of an Information System

Figure (2.3) is a schematic representation of the essential parts of an information system. The five basic parts are listed in the table that follows:

	Information System Name	General System Function
1	Information source	Source element
2	Coder	Operational element
3	Transmission or processing component	Transfer or operational element
4	Decoder	Operational element
5	Information receiver	Acceptor element

It should also be understood that a conversion element is always associated with an information system because information has no existence independent of energy or material.

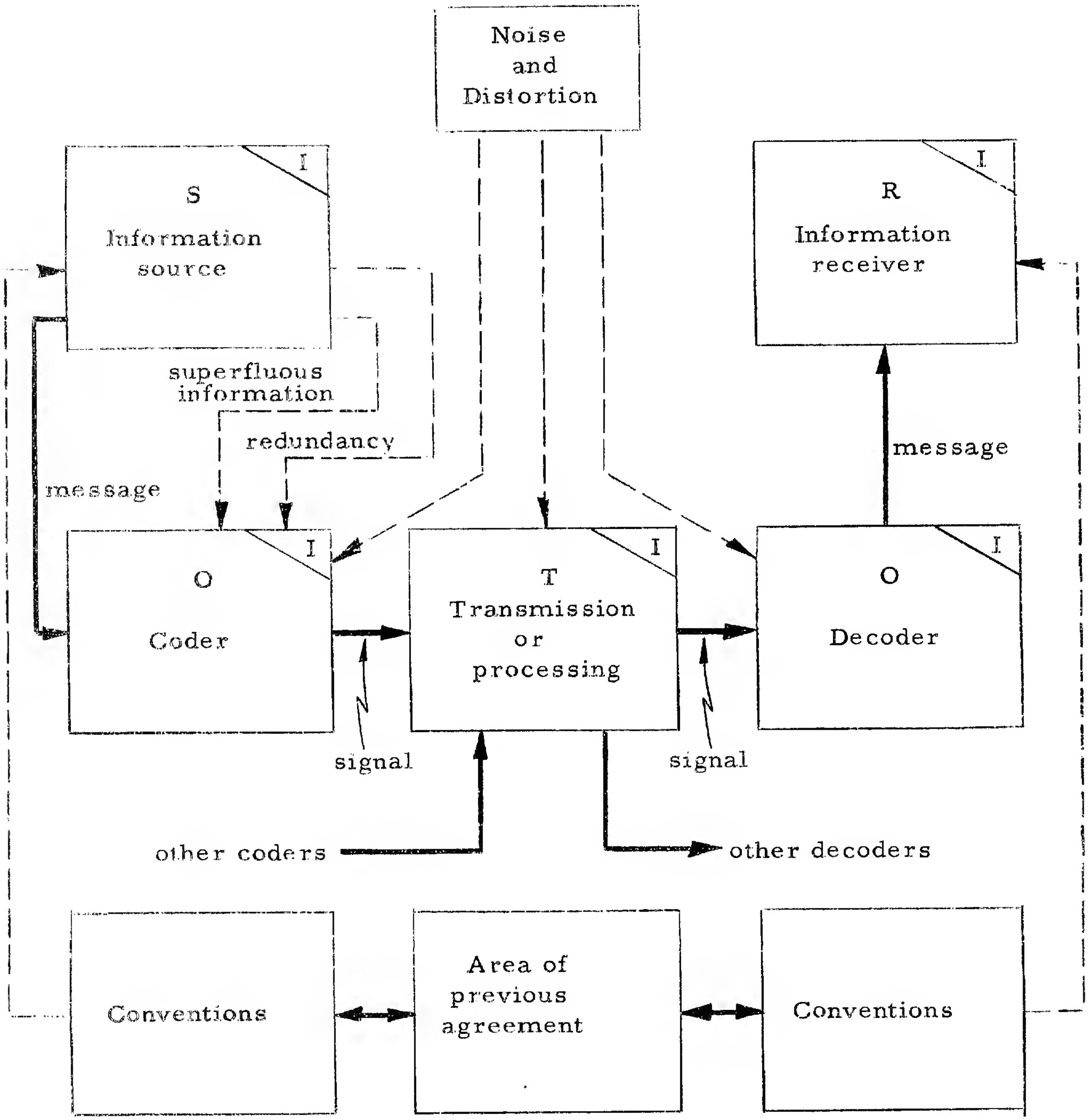

Figure (2. 3)

Classical (slightly modified) symbolic model of the essential ingredients of a one-way information system

When we consider information sources in detail, we find, in the limiting case, that there are only two fundamentally different types:

(1) the brain of a man

(2) changes in physical environment near some perceptor of information.

While we ordinarily take it for granted that certain types of information originate in the brain of man, the process by which this is accomplished is quite mysterious.

The second class of information sources refers to information developed through instrumentation of physical processes. Some perceptor of environmental change (or information) such as a microphone, radio antenna, thermometer, etc. is placed in an environment to keep some one of its properties under surveillance.

As in the case of information sources, we find that there are only two general classes of information receivers:

(1) the brain of a man, or

(2) a physical device which can respond to the information.

The information generated by the source constitutes the message to be transmitted or processed. However, the message is seldom in a form suitable for direct transmission to the receiver

nor is it usually in a form that lends itself to processing. It is usually necessary to code the message into a "signal" which has properties more suitable for transmission or processing. Coding is a general term used here to denote conversion of a message into a signal, or alteration of the form of the signal, according to some pre-determined plan. In ideal coding, the information contained in the message is preserved in the signal, only the form is altered. A consideration of this concept will be presented in more detail later.

As an example of the coding requirement, because direct telepathic communication between two brains is not reliably probable, the images in the brain of one man are not directly usable for transmission to the brain of another man. Instead, men commonly code their mental images into spoken words. The acoustical form of the signal can be transmitted through the air to the ear of the listener to be interpreted.

Of course, the coded information, or signal, has no meaning to the receiver until it is decoded according to some scheme previously agreed upon by the source and receiver.

The transmission and processing of information are always complicated by factors originating either within the system or from other factors external to it. For example, informational errors and ambiguities are introduced into the system through the presence of

noise and distortion. Similar difficulties are caused by interference originating in the presence of similarly coded signals in the transmission system when it is used for more than one information channel.

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Redundancy is often used by the information source to promote better understanding of the message. In this process the same information is transmitted more than once with the same or different coding.

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at the receiver. Here again, this factor may be used in the countermeasures effort, hence "jamming" or "spoofing" the system.

A system of accepted convention, although not a physical part of the system, is essential if the message is to be evaluated by the receiver. In other words, if the source speaks German and the receiver understands only English, communication is not achieved. Some prior agreement must exist between the source and receiver.

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1.2.4 Human Information Systems

Human beings constitute the most highly developed and complicated information systems presently in existence. This section is included at this time, although at first it may seem to contain irrelevant subject matter. Many of the aspects present in a human system bear considerable direct significance in surveillance problems but, more appropriately than that, its description permits the introduction of concepts to be used with effectiveness in the principal areas of interest.

Although many of the processes involved in human information systems are matters of pure conjecture, every element involved in every information system may be illustrated through reference to some part of the human system. As a very elementary beginning, we will consider some of the very gross aspects involved in oral communication from man-to-man using the system model described in Figure (2.3). A more sophisticated elaboration of certain human processes will be presented later, particularly with reference to closed loop systems.

Through the various sensory organs of the body, vast quantities of data and abstract notions are continually being transmitted to the brain. By some process, either electrical or electrochemical, the information is stored in the memory banks of the brain. Parts of

this stored information, in random arrangements, constantly parade themselves before the conscious mind in a continuing jumble of assorted mental images. Under the power of directed thinking, a pattern of thoughts is established which penetrates and occasionally replaces the random jumble of images. This pattern of thoughts or images constitutes a message which represents some measurable amount of information.

By a totally unknown process, this pattern of mental images is converted into word symbols according to conventions agreed upon with the second person in the conversation. This constitutes the first coding operation because the message, or abstract idea, has been converted into symbolic form different from the form of the original idea. This is illustrated in Figure (2. 4).

The brain converts these word symbols into electrical nerve impulses, or signals, in a second coding operation. This is an extremely complicated, multi-channel operational process. The nerve impulses, or signals, are transferred in space, and with some associated transfer in time, to the throat, facial, and abdominal muscles causing variations in the energy of the air blown across the vocal chords. This produces the acoustical signals of speech by a

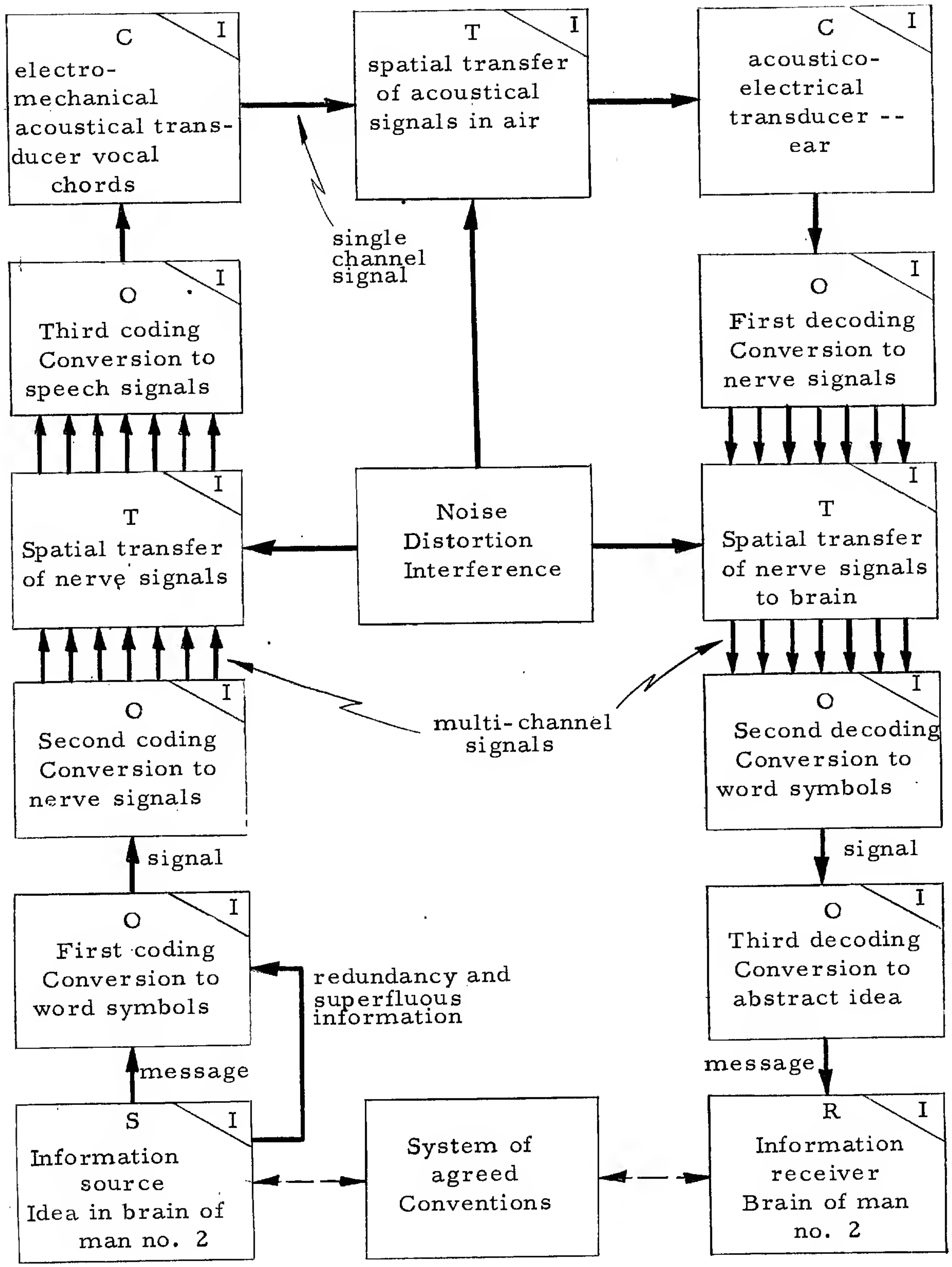

Figure (2. 4)
Detailed Breakdown of a Human Communication System

third coding* process which is accompanied by energy conversions from electrical to acoustical form; speech is a coded form of the original message. These various processes are illustrated in Figure (2. 4).

As shown in Figure (2. 4), the speech sounds are transferred in space (and time) through the air to the ear of the second man. The vibrations of the ear mechanism produces electrical impulses in the first decoding process. This is a highly involved operational process. The input to the ear is a single channel of information which contains both frequency and amplitude information as a function of time. The output of the ear has a multiplicity of channels: each output channel appears to contain amplitude information only, over some restricted range of frequencies. This multi-channel collection of electrical nerve signals is transmitted through the auditory nervous system to the brain where it is interpreted, in the second decoding, as word symbols. If the words used by the first man are properly chosen in accordance with the agreed upon conventions, the word symbols evoke, with varying degrees of exactitude, mental images in the brain

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*Although the term "coding" is used in this third case, it may be preferable to call it "modulation", wherein high speed variations of the air molecules are caused to vary in proportion to the speech signal.

of the second man corresponding to the images in the brain of the first man. This evocation of mental images constitutes the final decoding operation.

The complete communication system is shown in very simplified block diagram form in Figure (2. 4).

The information received by the second man is stored in the memory section of the brain--stored in association with a qualitative scale of human values derived from his relation to his social and cultural environment. The higher logic centers of brain compare this new information with respect to the stored value evaluating the worth, relevancy, adequateness, and utility of the information.

It is clear from this discussion that the block marked as the coder may involve several distinctly different coding operations. Thus, when we look at any system in detail, we find multiplicity of coding, decoding, and transmission.

There are many other interesting aspects to this problem of communication from one man to another. Some of the more obvious factors are the following:

(1) Communication may be complicated by imperfections in the system of agreed conventions, differences in vocabulary or value system.

(2) Through poor word selection or superfluous expressions, the idea evoked in the brain of the second man may be quite different from the original thought.

(3) Inaccuracies in message transmission may result from distortion produced by slurred speech or imperfect hearing.

(4) The presence of background noise or other conversations may inhibit the transfer of the message.

A course presentation of the detail in Figure (2. 4) is shown in Figure (2. 5).

The second type of information handling involves the processing function as its primary characteristic rather than communication as in the previous example. In this case, we take certain items of information and perform mathematical or decision making operations to produce new information, or new interpretations of old information.

1. 2. 5 Feedback in Human Information Systems

In the preceding section, very elementary considerations of human information systems were used to underscore the importance of

(1) coding and associated operational functions

(2) energy conversions

(3) information transfer processes and media.

This importance is further emphasized in Figure (2. 6). This figure

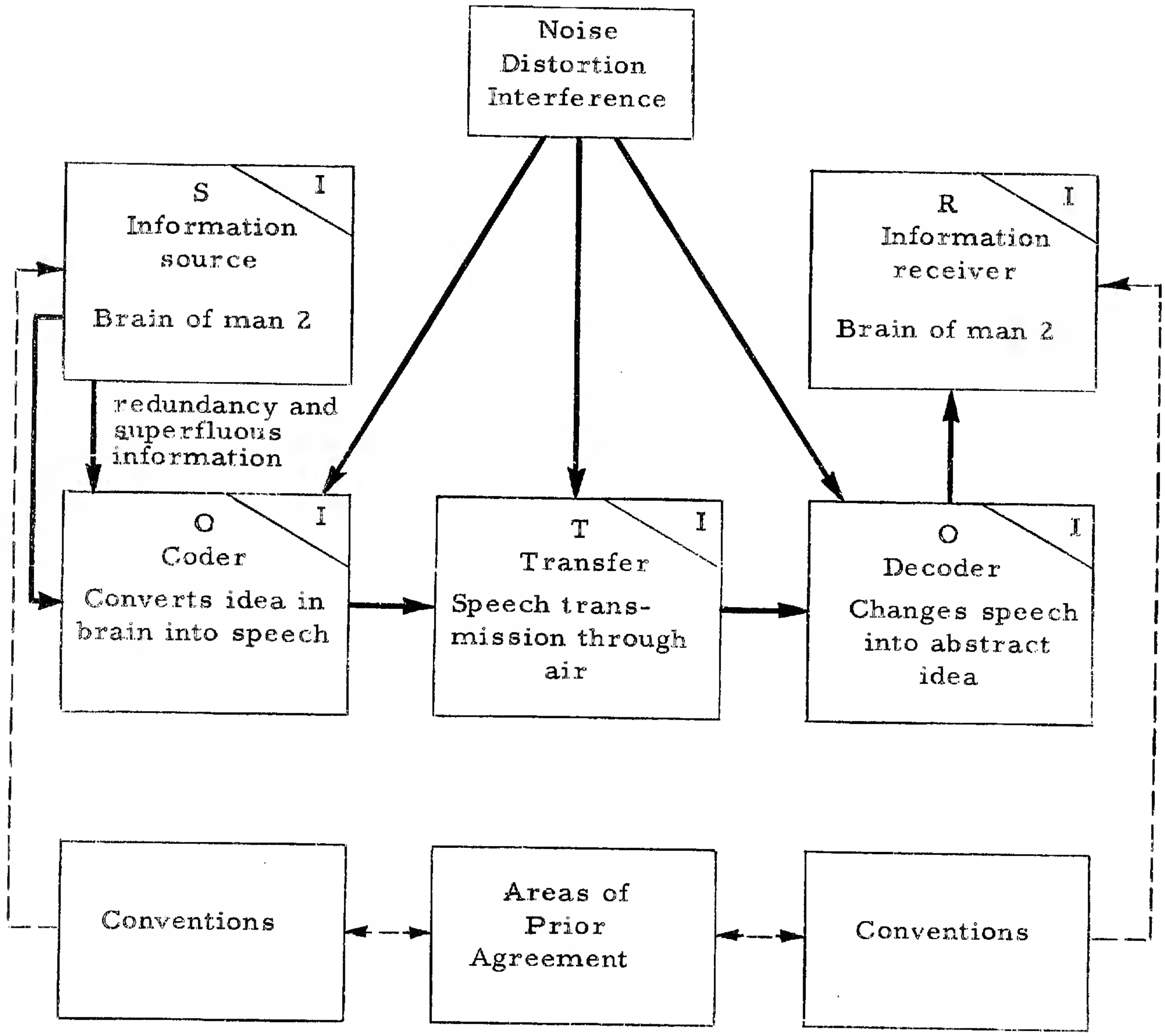


Figure (2. 5)

Coarse representation of a human communication system derived through simplification of the detailed description shown in Figure (2. 4).

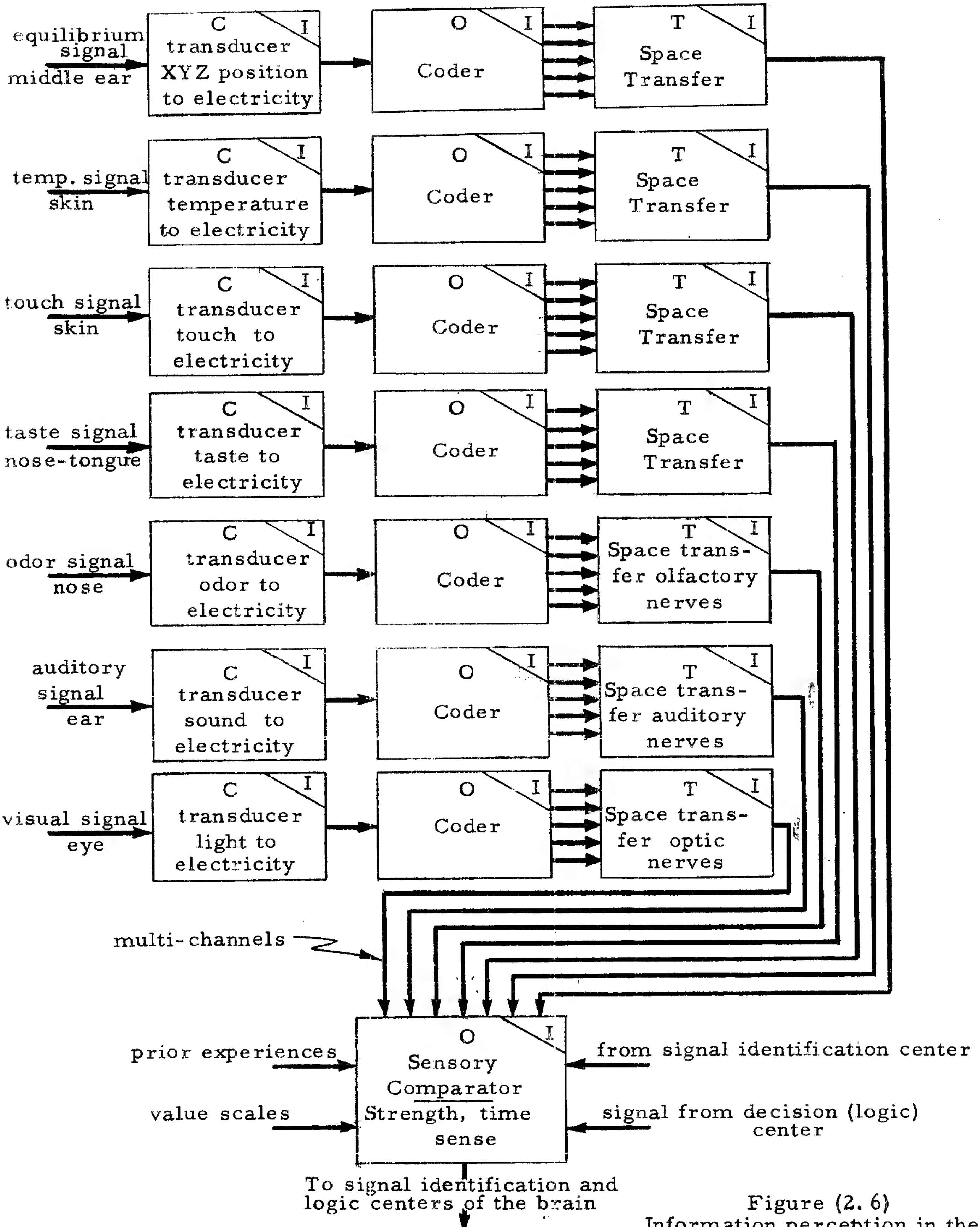


Figure (2.6)
Information perception in the human communication system

shows the basic connection between the brain and all of the information perceptors available to the normal human. All of the seven sensory elements are composed of an energy converter and a coder. Each is connected to the brain by the nervous system which serves to transfer the information perceived. All of these signals enter the first principal element of the brain, an element we will call the sensory comparator.

Figure (2.7) shows a very simplified system model of the brain, serving to illustrate the principal functions performed. The information perceptors deliver nerve signals concerning some physical situation to the sensory comparator, the first operational element of the brain. The sensory comparator has three functions:

(1) it stores the perceived information temporarily in a short time memory bank,

(2) it sends the information to the second identifying comparator,

(3) it sends instructions to the memory scanner to look through the main memory banks for similar information.

The memory scanner examines the main memory banks for data previously stored concerning similar information, data relating to both value scales and actual situations.

The output of the memory scanner is fed to the higher order

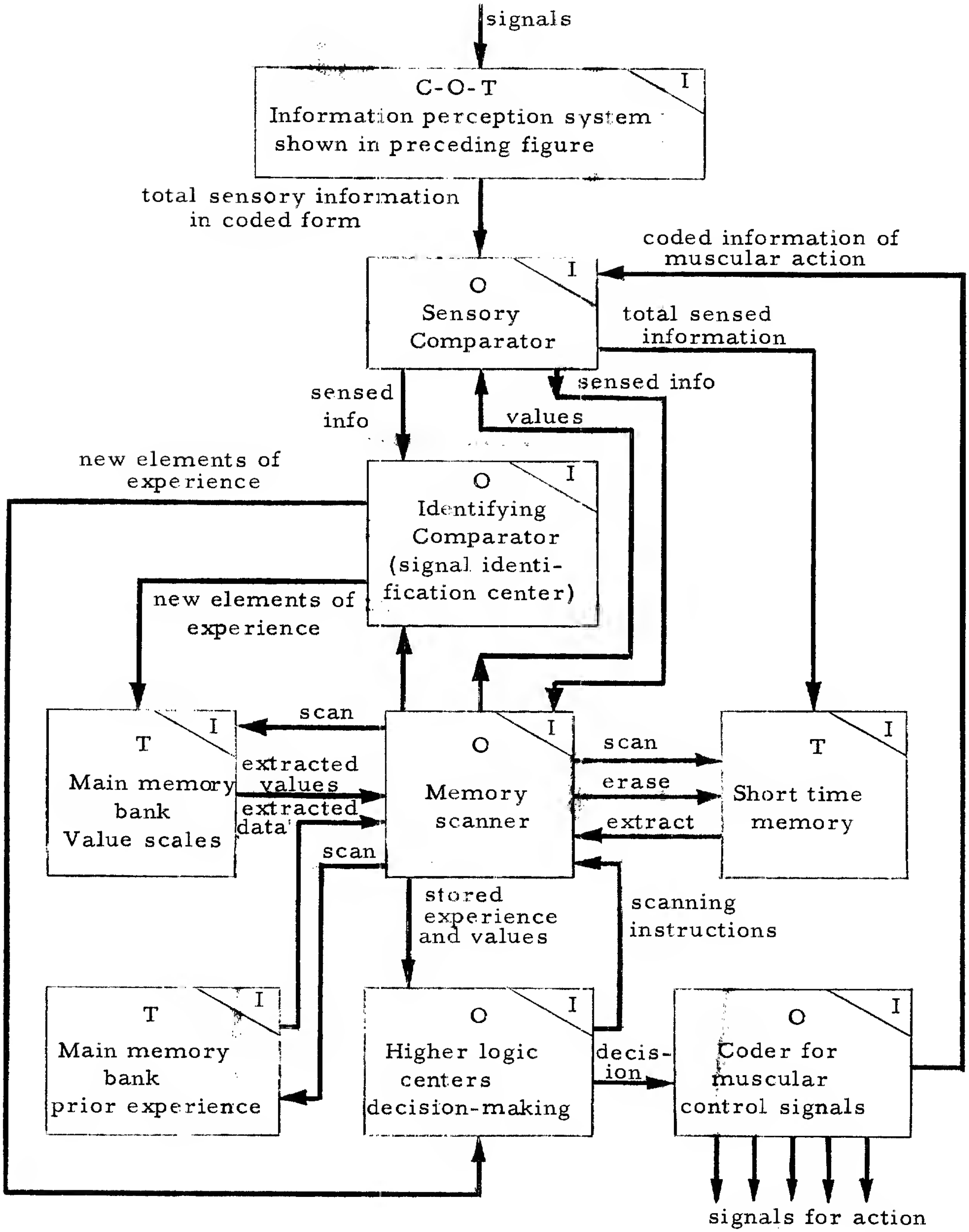


Figure (2. 7)

Closed loop, or feedback, characteristics of the human brain shown in highly simplified form.

center which, in turn, reacts back upon the scanner tending to direct its search of the memory banks in a controlled pattern rather than in a random manner. The output of the memory scanner also goes to the identifying comparator. Here the information extracted from memory is compared against the new sense impression and identified, if possible. The new information, which is that part of the incoming information without a counterpart in that extracted from memory, is then delivered to the main memory bank for storage.

In the meantime, the higher order logic centers have come to a decision based upon the memory scanning and the new elements of the situation, and have sent signals throughout the body directing various muscles to perform certain tasks. The same information is sent to the sensory comparator so that it will constantly compare the changes in the incoming information with the plans originated by the logic centers.

There are many other related aspects, of course; this is a very crude picture.

However, the principal point is clear: the system has a multiplicity of closed loop signal paths. In short, it is a multi-loop feedback system. While, at this stage in our analysis, this has been established only in connection with human information systems, it is a fundamental property of all systems. Particularly will this be true of positive surveillance systems and their countermeasure systems.

1.2.6 Feedback in Two-Way Information Systems

Previously we discussed simple communication from one man to another. This is a one-way, or unidirectional, information system. This type of system has been explored with greater success than the more complicated problems posed by two-way, or bi-directional, information systems. A schematic representation of a simplified bi-directional system is shown in Figure (2.8). This is the most common type of system.

In the bi-directional system, there is an interchange of messages between two individuals. As a result it is possible to change the "conventions" during transmission. This two-way flow of information serves two purposes:

(1) it acts to correct transmission errors and

(2) to remove misunderstandings from the "conventions".

From the very structure of the system, it is clear that this process has strong "feedback coupling" which affects all of its essential properties, rendering it quite different from the unidirectional system.

The concept of counter-countermeasures probably falls most appropriately into this type of information system. Much more will be said about this subject later.

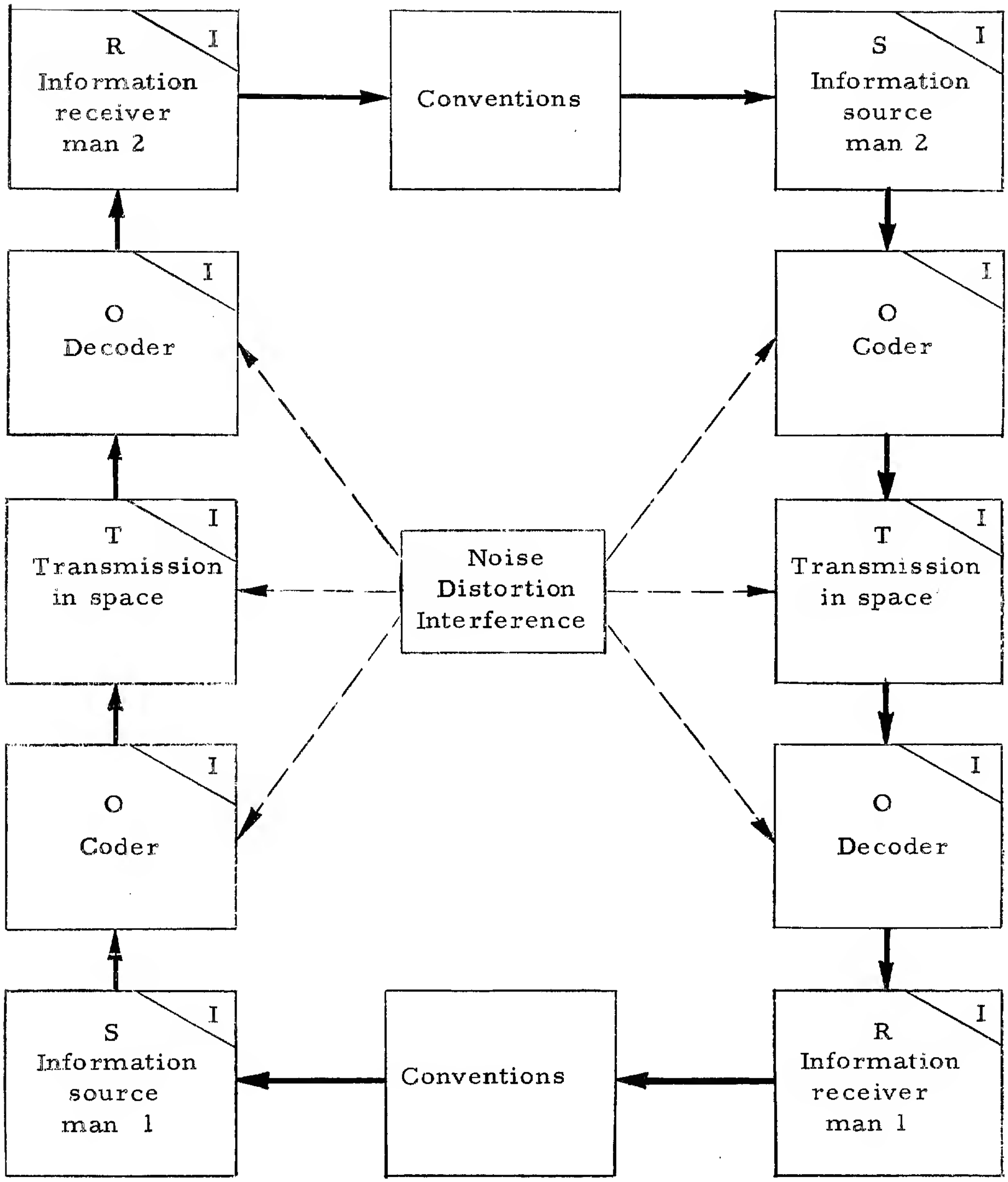


Figure (2.8)

Intrinsic feedback in two-way communication

1.2.7 Enter Electrical Machine Aids

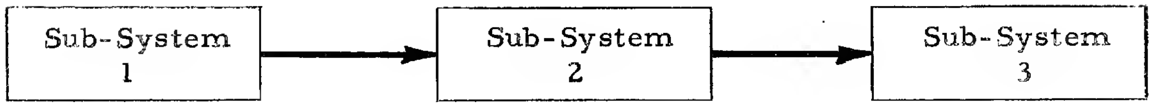
The human information system is exceedingly complicated. The complexity is internal to the human, arising in the many mysterious coding, logic, and memory functions.

The information requirements of human society are beyond the capabilities of the human system. Inevitably machine aids are required to achieve mass communication, control of other machines, communication over large distances and long time intervals, for rapid calculations and under adverse and diverse conditions such as encountered in surveillance and its countermeasures.

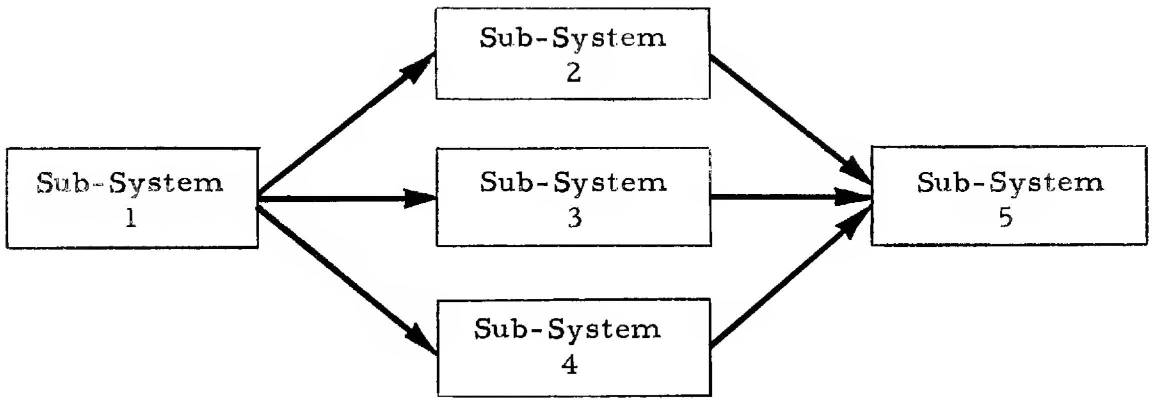
When machines are used for the purposes enumerated, they become sub-systems, or fragmentary parts of some larger system. Each sub-system possesses the five essential function elements as shown in Figure (2.3). Figures (2.9) and (2.10) show several arrangements of sub-systems in a larger system.

When a machine aid or sub-system is introduced into a larger system, it is very often electrical in character. Other types of sub-systems will be discussed specifically if they arise in the general surveillance discussions. There are several reasons for the importance of electrical sub-systems:

(1) compared to signals in other media, it is nearly always true that electrical signals have a higher degree of trans-



straight tandem connection



parallel tandem connection

Figure (2.9)

System sub-division into separate sub-systems, each possessing the five essential elements shown in Figure (2.3).

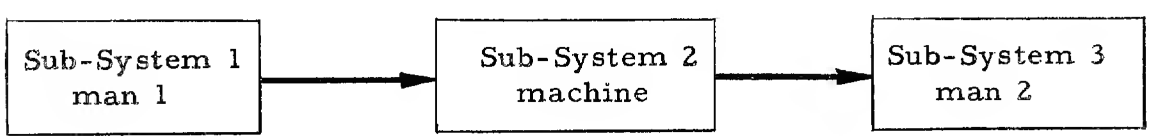


Figure (2.10)

Machine aided human communication

portability in space.

(2) electrical energy systems are more readily coupled to other media than are other energy systems (light and acoustical systems are possible exceptions).

(3) electrical signals are more readily coded and modulated.

(4) because of the comparative ease of coding, there are more coding possibilities available for practical use.

Thus, except for very rudimentary systems, it is quite general practice to convert information into electrical signals to capitalize upon the desirable properties of electrical energy for the processing and transmission of information.

1.2.8 Coding and Modulation

Electronics and electronic circuits are important subjects precisely because they have the ability to perform operations, such as coding, which make machine aids possible and useful. This discussion can be simplified through common agreement on the definitions of coding and modulation:

(1) Coding -- the process of converting the form of information from one logic system or "language" into another.

(2) Modulation -- the process whereby some property of a carrier wave of a higher frequency than any component in

the information signal is varied in accordance with the time variation of the signal.

Electrical signals may be modulated by either of one or two distinctly different processes:

(1) carrier modulation -- a continuous process

(2) pulse modulation -- a discontinuous process.

In carrier modulation, some property of a high frequency wave is varied in accordance with the time variation of the modulating signal; the modulating signal is continuously operative upon the carrier. In pulse modulation, some property of a high frequency pulse train is varied in accordance with the time variation of the modulating signals; the modulating signal is operative only during discontinuous intervals. This implies the necessity for an additional coding step known as sampling.

A carrier wave (see Figure (2.11) represented by $i_c = I_c \sin(\omega_c t + \phi)$ has only two properties subject to variation by the modulating signal, the amplitude and angle. Therefore, two forms of carrier modulation can be identified as follows:

(1) amplitude modulation -- the variation of the carrier wave amplitude (I_c) is made proportional to the time variation of the signal. Herein the resulting signal contains "redundancy". The information can be transmitted as

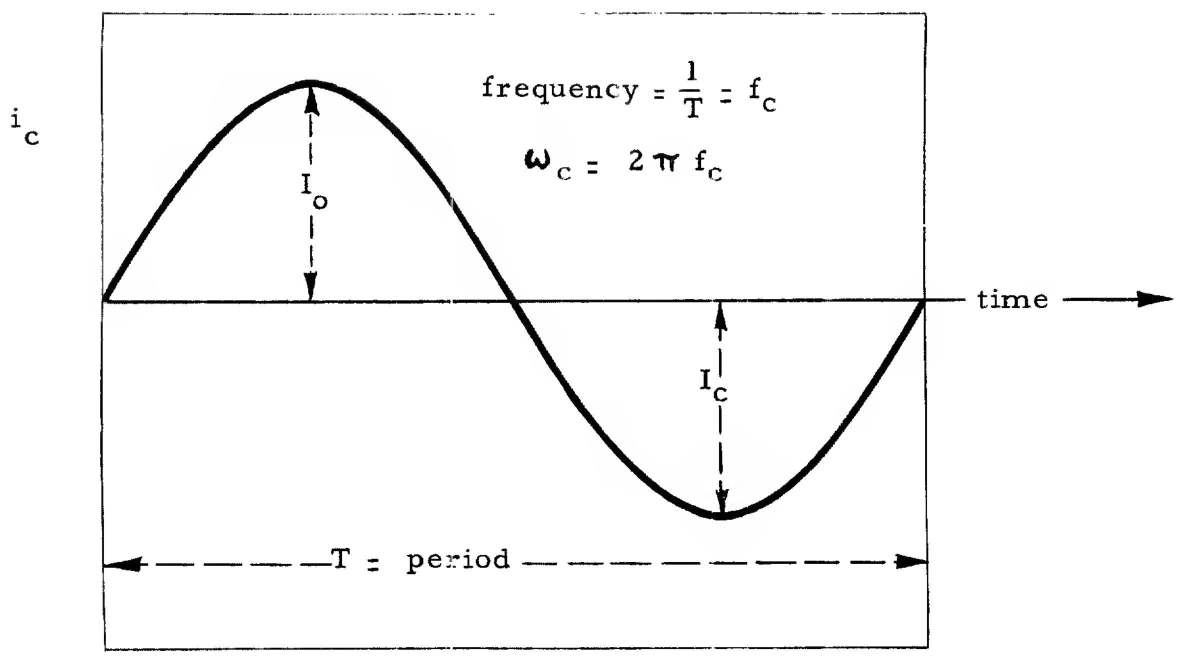


Figure (2. 11)

Essential elements of a carrier current

well by selecting part of the result which is then known as "single side-band modulation".

(2) angle modulation -- the variation of the carrier angle (ω_c) is made proportional to the time variation of the modulating signal.

At any instant of time, the angle of the carriers in dependent upon the frequency. Thus we distinguish two types of angle modulation:

(1) phase modulation -- the angle (ϕ) is made to vary in direct correspondence with the time variation of the modulating signal.

(2) frequency modulation -- the frequency (f_c) of the carrier is made to vary in direct correspondence with the time variation of the modulating signal.

The three types of carrier modulation are frequency, phase, and amplitude modulation or FM, PM, and AM.

A high frequency pulse train is shown in Figure (2.12). Such a wave train is described by the pulse frequency, position, width, and amplitude. Therefore, we recognize four pulse modulation possibilities:

(1) pulse amplitude modulation	PAM
(2) pulse width modulation	PWM
(3) pulse position modulation	PPM
(4) pulse frequency modulation	PFM

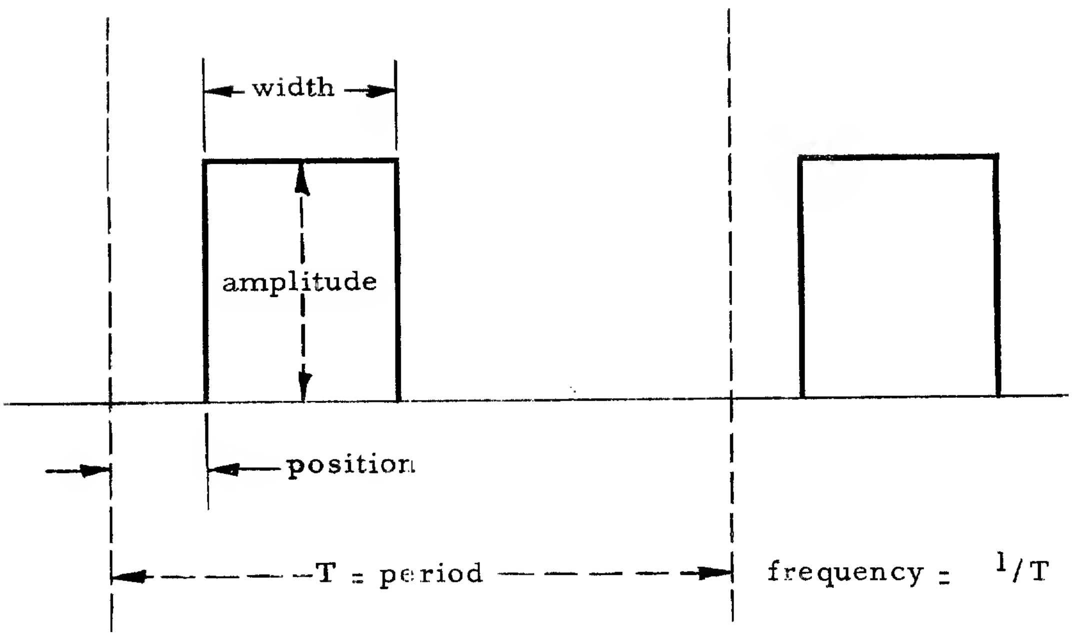


Figure (2. 12)

Essential characteristics of a pulse train

In each case, the particular property of the pulse train is made to vary in direct correspondence with the time variations of the modulating signal. In this class of modulation, the modulating signal is operative only during some specified period corresponding to the pulse duration. Hence, this is a discontinuous modulation process in contrast to the continuous characteristic of carrier modulation.

This now gives us seven modulation possibilities to be concerned about, i.e. three types of carrier modulation and four types of pulse modulation. In many cases, depending upon the type of information system and transmission system, it is found that a single modulated signal does not make maximum use of the transmission channel capacity available. When this occurs, it is customary to multiplex the signals. There are two distinct types of multiplexing:

(1) frequency division multiplexing -- each signal is associated with a separate carrier frequency and all are transmitted at the same time - multiplexing in frequency domain.

(2) pulse time division multiplexing -- samples of each signal are transmitted in time sequence at a high sampling frequency in the same frequency band.

It is possible, obviously, to use both frequency division and time

division multiplexing in one channel, with seven modulation possibilities thrown in for good measure.

The problem does not end here. There are many applications where privacy considerations are important, or where special attention must be given to reduction of signal deterioration by noise. When these conditions are present, the signals are coded before modulation and multiplexing.

(1) continuous coding -- speech scramblers and similar techniques

(2) discontinuous coding -- pulse code modulation PCM for example, of the incoming signal has components up to a frequency (f_o), it is first sampled at a rate greater than ($2 f_o$). This yields a lot of pulses continuously modulated in amplitude. The amplitudes of the pulses are quantized, and assigned to one of a finite set of such levels. The quantized signal triggers a pulse generator which generates a binary coded signal. The specific binary number generated depends upon where the sampled signal falls among the various quantized levels.

Each of these processes is clearly coding, rather than modulation, because wholly new signal forms are generated; there is no process here wherein one property of a wave is varied analogously in

accordance with the time variation of the signal. On the contrary, the coded signal is an entirely new signal form.

1.2.9 Machine Sub-Systems and Their Analysis

To analyze a specific sub-system, one should perform the following functions:

(1) resolve the general equipment requirements into detailed specifications of equipment functions,

(2) select the coding, modulation, and multiplexing arrangements to be used and specify their detailed technical properties,

(3) select and define the transmission media and processes,

(4) select and define the properties required of information perceptors and receptors,

(5) establish criteria for equipment reliability,

(6) establish limits allowed for equipment error.

These functions also require a knowledge of the principles derived from information theory, electronic component and circuit design.

1.2.10 Electronics and Electronic Circuits

From the tenor of previous sections, it is apparent that the word "electronics" has become virtually synonymous with "information systems". This is so because the machine aids to communication

and processing are nearly always electronic in character. In most cases, the requirements imposed by the modulation and coding processes are such that only electronic circuits possess the requisite properties. For the sake of the record, the essential topics in electronics and electronic circuits are summarized here.

Electronic devices, as used here, include vacuum and gas tubes, varistors, thermistors, transistors, cryotrons, magnetic and dielectric amplifiers, etc. Such devices characteristically possess either one or both of the following properties:

(1) they are amplifiers or

(2) they can be used as very high speed, synchronous, switches. An amplifier is a circuit whose output is an enlarged reproduction of the input, and the power developed in the output is drawn from a source other than the input. An analysis of electronic devices requires an analysis of these two properties from the two following aspects:

(1) a study of the physical devices which provide the two basic properties listed and

(2) a study of the physical phenomena incorporated in these devices. This includes dynamics of charged particles, conduction in gas, solid state, atomic, and nuclear physics.

When electronic devices are combined with other electrical

elements in different circuit configurations, and operated as amplifiers or switches, the resulting electronic circuits are capable of performing an incredible number of operations. Although the variety of such circuits is nearly endless, they fit into five basic categories, as follows:

(1) amplifiers

(2) oscillators

(3) diode switching circuits

(4) modulators

(5) digital and logic circuits.

These various categories of electronic circuits form the basic building of the machine aids to information processing.

1.3.0 Energy and Power Systems

Although existing equipment systems use many, if not all, of the physically different energy forms, particular attention herein has been concentrated in electrical energy systems. This means that energy may originate in any form but we may assume in these preliminary discussions that it is converted into electrical energy for transmission and distribution.

1.3.1 Basic Properties of Power Systems

The words "power systems" include all systems whose primary

functions involve the transfer of electrical energy in space or time. In fact, most technical systems, regardless of size or complexity, require an associated power system.

At first thought an adequate description of a power system would seem to involve only a power source connected to a receptor through a transfer medium. However, when the problem is examined more carefully, the system description indicated in Figure (3. 1) results. This shows that all power systems are composed of five major functional elements:

(1) energy reservoirs

(2) energy converters

  (a) to convert the form of the energy coming from the reservoir to electrical energy

  (b) to convert the electrical energy emerging from the transfer medium to the energy form desired by the receptor.

(3) energy transfer system to transfer energy in space or time

(4) sources of environmental disturbances

(5) an information, control, or protective system.

The necessary inclusion of an associated information channel with every power system always produces a closed loop system.

This closed loop characteristic results from an important

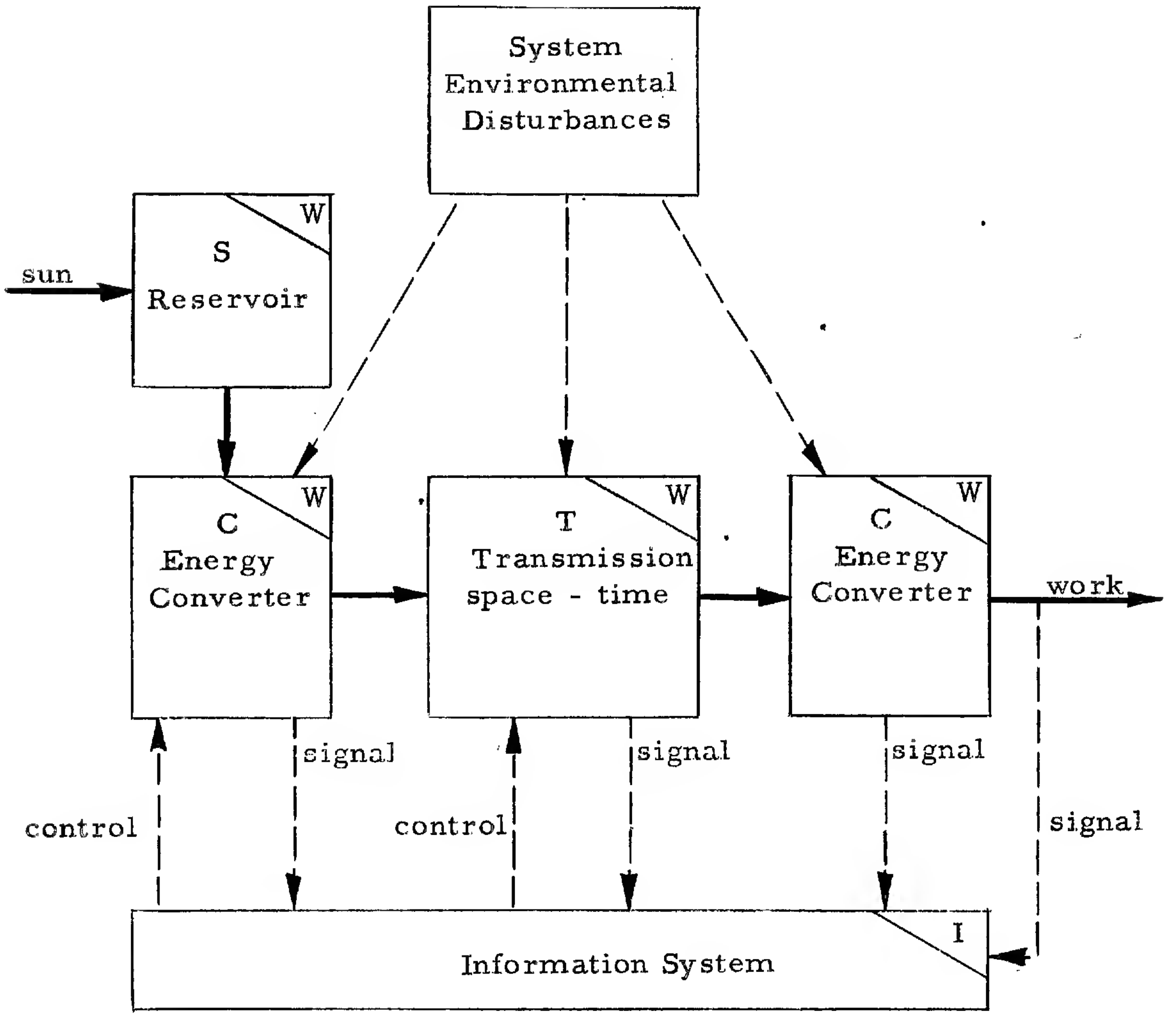


Figure (3. 1)

General power system

property of power systems that is uniquely different from the basic characteristic of the general information system. The difference is this: In information systems the amount of information entering the transfer medium is controlled by the source; in the power system the amount of power entering the transfer medium is controlled primarily by the receptor. Because the receptor controls the power flow from the source, the system is intrinsically closed loop in character.

1.3.2 Energy Reservoirs - Primary and Secondary

For all practical purposes, the sun may be considered as the primary reservoir of all energy available on the earth. Likewise, for general layman purposes, by a series of natural energy conversion processes, the energy from the sun has been altered and placed in secondary reservoirs of the following types:

(1) fossil fuels,

(2) nuclear fuels,

(3) chemical reactions,

(4) wind and water power, and

(5) lunar-ocean tides.

Each of these stores energy in one form or another, either as:

(1) light

(2) heat,

(3) kinetic energy,

(4) mechanical energy, and

(5) electricity in a few rare cases.

The inter-relationship between the various reservoirs are indicated by the schematic diagram in Figure (3. 2).

To provide a more complete and scientific approach to the energy problem, let us turn back to fundamentals and ask more specifically, "What are the sources of energy available in the universe?" Without treading on controversial ground, we are safe to say that there are three natural sources of energy. These are contained

(1) in the nuclei of atoms,

(2) in the extra-nuclear structure of atoms and molecules,

(3) in the incoherent motion of the molecules of matter in bulk.

These three forms are known as nuclear energy, chemical energy and heat energy. In the case of both nuclear energy and chemical energy, liberation is brought about when "fission" or "fusion" occurs, in each case with the evolution of more stable "substances".

Although there are only three <u>sources</u> of energy in the universe, we are accustomed in our scientific investigations to define the forms of energy in a manner more suitable for our current investigation.

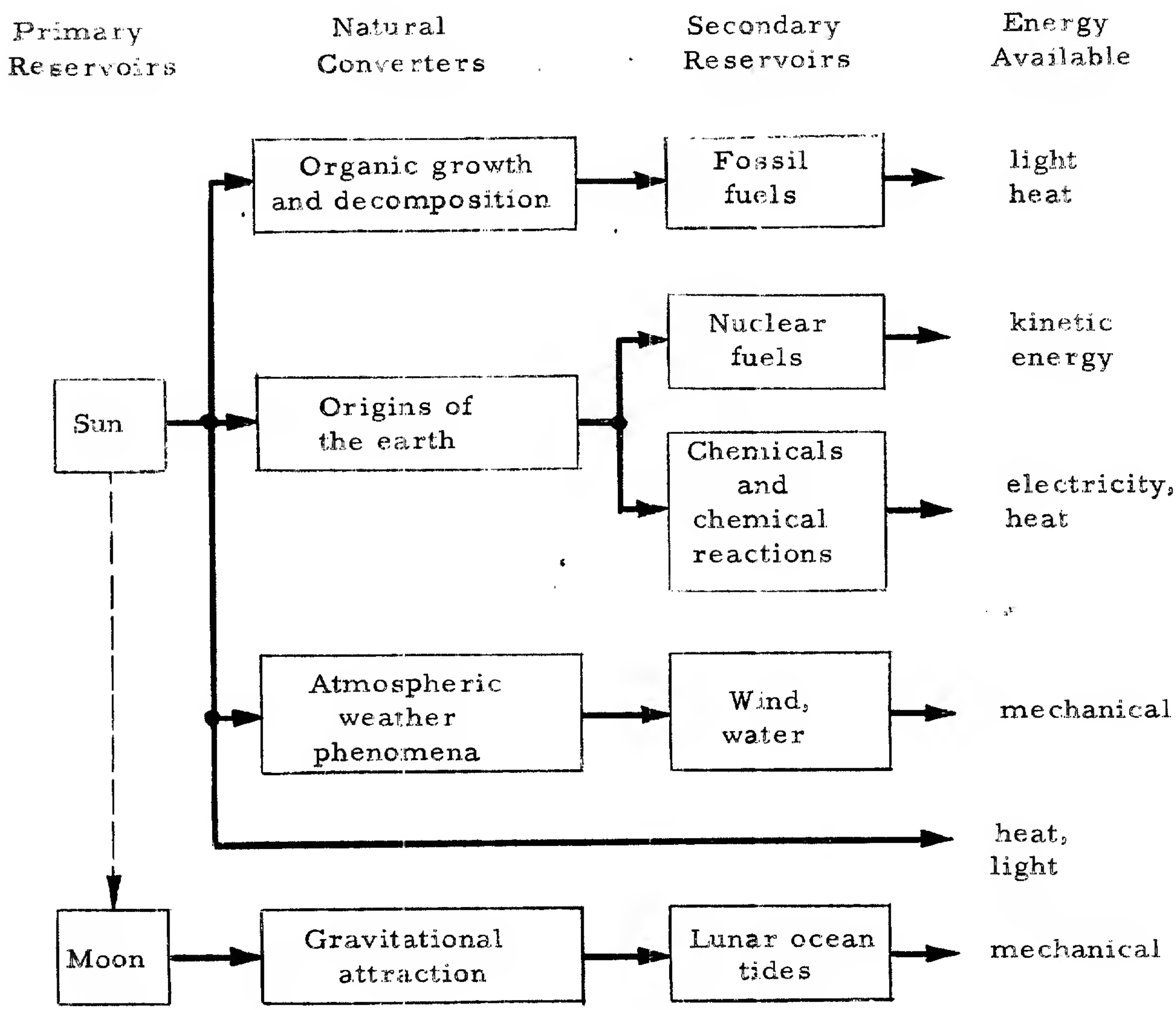


Figure (3. 2)

Energy reservoirs

First, we have nuclear energy, which can give rise to high speed particles and electromagnetic radiation of very short wave-length.

Secondly, there is atomic energy, comprising the energy associated with the electronic structure of atoms and appearing in chemical reactions. This energy is only available in exchange processes. Arbitrarily, electromagnetic energy and the particles which may be emitted from the atoms and molecules are not included.

Thirdly, there is microkinetic energy, comprising the energy associated with moving charged particles by virtue of their velocity and mass. We find this energy in particle accelerators, in x-ray tubes and in certain thermionic tubes. Nuclear and atomic energy are often converted into microkinetic energy in the form of fast moving electrons or positive ions.

Fourthly, there is static electromagnetic energy by which we understand the energy associated with electrical circuits. This form comprises two sub-divisions:

(1) electrostatic represented by $\frac{1}{2} C V^2$ and

(2) magneto-static represented by $\frac{1}{2} L I^2$

where $V =$ voltage, $I =$ current, and C and L represent capacitative and inductive parameters.

Fifthly, there is radiant electromagnetic energy, which is associated with variable electric and magnetic fields in free space and comprise radio, infrared, visible, ultraviolet, and X and (γ) waves. When such energy interacts with matter, we lose sight of the electric and magnetic fields and become conscious of the photon of energy ($h\nu$).

Sixthly, there is coherent molecular energy or elastic energy, associated with the elastic forces of matter in bulk. The source of this energy is chemical.

Seventhly, there is non-coherent molecular energy, which is merely another name for heat energy associated with matter in bulk.

Finally, there is the energy associated with microscopic mass by virtue of its speed or position. It is commonly referred to by the names kinetic and potential energy.

Transducers are devices which change one of the forms of energy just mentioned to another. It is, therefore, possible to construct a chart (see Figure 3.3) having the various forms of energy at the heads of eight columns and the same forms of energy at the heads of eight rows, and every physical or chemical effect shown in an appropriate square in the chart. To take several simple examples, the Peltier effect transforms heat to electrical energy; a loudspeaker

CONVERSION FROM

CONVERSION TO

TYPES OF ENERGY	NUCLEAR	ATOMIC	ELASTIC	HEAT	STATIC ELECTRO-MAGNETIC	RADIANT ELECTRO-MAGNETIC	MICROKINETIC	MACROSCOPIC KINETIC
NUCLEAR		DIRECT ACTION IS IMPOSSIBLE	DIRECT ACTION IS IMPOSSIBLE	ABOVE 10[illegible] DEGREES KELVIN	NOT ENTIRELY IMPOSSIBLE	TRANSFORMATION BY MEANS OF GAMMA RAYS	TRANSFORMATION BY MEANS OF PARTICLES	IMPOSSIBLE IN LABORATORY
ATOMIC	RADIOACTIVE TRANSFORMATION (A BY-PRODUCT)		DIRECT ACTION IS IMPOSSIBLE	THERMAL COMBINATION, DISSOCIATION and EXCITATION ENDO-THERMIC REACTION	STARK EFFECT ZEEMAN EFFECT ELECTRIC DISCHARGE	PHOTOCHEMICAL REACTIONS	CHEMICAL CHANGE BY PARTICLE BOMBARDMENT	DETONATIONS BY IMPACT (?)
ELASTIC	NO APPARENT DIRECT ACTION	CRYSTAL FORMATION		CRYSTAL FORMATION	PIEZOELECTRICITY FERROELECTRICITY MAGNETOSTRICTION (LOUD-SPEAKERS)	MODIFICATIONS TO MOLECULAR STRUCTURE	MODIFICATIONS TO CRYSTAL STRUCTURE	GENERATIONS OF ELASTIC OSCILLATIONS
HEAT	NO DIRECT ACTION BUT FINAL FORM	EXOTHERMIC REACTION (EXCESS)	ATTENUATION AND SUPERSONIC HEATING		RESISTIVE LOSSES	ABSORPTION AND DEGRADATION	BOMBARDMENT OF MATTER IN BULK	FRICTION AND VISCOSITY
STATIC ELECTRO-MAGNETIC	MAY OCCUR BUT UNKNOWN	VOLTA EFFECT	PIEZOELECTRICITY FERROELECTRICITY MAGNETOSTRICTION (MICROPHONES)	PELTIER EFFECT		RADIO FREQUENCY RECEPTION	SPECIAL HIGH TENSION SUPPLIES	DYNAMICS, ETC.
RADIANT ELECTRO-MAGNETIC	GAMMA RADIATION	CHEMICAL EXCITATION OF RADIATION	FEASIBLE BY MEANS OF THREE EFFECTS ABOVE	RADIATION FROM A HOT BODY	RADIO FREQUENCY EMISSION		X-RAY TUBE ALPHA or BETA-RAY TRANSFORMATIONS WITH GAMMA EMISSION	POSSIBLE PERHAPS IN THE FUTURE
MICROKINETIC	ALPHA AND BETA PARTICLES NEUTRONS MESONS	CHEMICAL IONIZATION	AN EFFECT SHOULD BE POSSIBLE	THERMIONIC EMISSION MOLECULAR BEAM	FIELD EMISSION HALL EFFECT PARTICLE ACCELERATIONS	PHOTO EMISSION GAMMA RAY TRANSFORMATION WITH ALPHA AND BETA EMISSION		ONLY VIA CHEMICAL ACTION
MACROSCOPIC KINETIC	FINAL PRODUCT IN NUCLEAR ENGINE	FINAL PRODUCT IN I.C. ENGINE	SPRING MOTOR OR ELASTIC MOTOR	STEAM ENGINE	ELECTRIC MOTOR	RADIATION PRESSURE EFFECTS	PRACTICAL APPLICATIONS FEASIBLE	

Figure (3.3)

transforms static electromagnetic energy into elastic energy or acoustic sound waves.

Even the most cursory examination of this table shows that an enormous variety of physical phenomena are involved in these conversion processes. Accordingly, the cross-hatching in Figure (3. 3) is included to eliminate energy transformations which are not believed to be significant and pertinent to the surveillance and countermeasures program. Only those squares which are not cross-hatched are believed to be worthy of detailed consideration at the present state of technology.

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1.3.3 Bandwidth and Channel Capacity

In 1928, Hartley [1] generalized earlier results relating to bandwidth and channel capacity; and among his conclusions, he stated: "The total amount of information which may be transmitted over a system whose transmission is limited to frequencies lying in a restricted range is proportional to the product of the frequency range which it transmits by the time during which it is available for transmission". We know now that this principle is true if carefully interpreted, but it should be kept in mind that certain assumptions are implied and some factors have been neglected. In certain instances, it has provided a ready means of checking whether claims for a complicated system lie within the range of physical possibility.

The modern theory of information, as developed by Wiener [2], Shannon [3], and others, provides a quite general basis for studying the connection between the purpose of a transmission and measurable technical characteristics of the transmission.

A transmission is useful only because it enables one to get information from one place to another. The information is trans-

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[1] R. V. L. Hartley, "Transmission of Information", The Bell System Technical Journal, Volume 7, No. 3, (July, 1928), 535.

[2] Norbert Wiener, Cybernetics, New York: John Wiley, (1948).

[3] C. E. Shannon, "A Mathematical Theory of Communications", The Bell System Technical Journal, Volume 27, No. 3, (July, 1948), 379, and Volume 27, No. 4, (October, 1948), 623.

formed into a signal, which is the variation with time of one or more characteristics of the transmission. The signal, or its modulation, represents information in the form of a message or by the variation of some quantity directly related to the information. In either case, these are the essential points:

(1) the information contained in a signal is represented by some measurable quantity which varies as time passes.

(2) a particular signal is a choice from the set of all possible signals. The larger is the number of signals which could be selected; the greater is the information contained in the particular signal selected.

The reason for discussing this is that there is a numerical relation between the rate at which information is transmitted and the minimum bandwidth required for transmission, thus relating the purpose of a transmission with at least one measurable technical characteristic of a signal.

Again, any type of signal can be reduced to the form of a quantity which varies with time; the question of how fast it varies with time is answered by specifying its bandwidth, W. A signal with a bandwidth (W) contains frequencies up to and including W cycles per second. Such a signal cannot change to a substantially new value in a time less than one-half cycle of the highest fre-

quency W. This means that we can describe such a signal by measuring its value at intervals of time $\frac{1}{2}$ W seconds apart; it is not necessary to transmit instantaneous values continuously in order to reproduce the original. A signal, which is limited to bandwidth W, can be reconstructed completely if its values at time intervals of $\frac{1}{2}$ W or less are known; that is, the signal must be sampled at every half-cycle or less of its highest component frequency. If the signal lasts for a total time of (T) seconds, there will be 2 TW samples available in this time. Then any signal limited to the bandwidth (W) and the time interval (T) can be specified by giving 2 TW numbers. The above comments are referred to as the Sampling Theorem in information theory. To determine the quantity of information that can be transmitted over a channel, additional factors must be introduced.

(a) any practical transmission system will not be able to handle signals of unlimited size. Let us state this limit in the form of an average transmitted power, P.

(b) each system can best be specified to an accuracy of the noise (N) in the system. (N) is also measured in power units and it is referred to as the noise power. This assumes that, for any two signals to be distinguishable, they must differ by at least the level of noise in the channel.

(c) if a signal has an average power, P, then the signal plus noise (P + N) will have a power (P + N) and an amplitude $\sqrt{P+N}$. The noise, of power N, will have an amplitude $\sqrt{N}$. The number of amplitudes that can be distinguished reasonably well is then:

$$\sqrt{\frac{P+N}{N}}$$

Any one of these amplitudes can be selected at each sampling interval, or each $\frac{1}{2}$ W seconds, for (T) seconds or for 2 WT sampling intervals. The total number of reasonably distinct signal levels in time (T) is then

$$M = \left\{ \sqrt{\frac{P+N}{N}} \right\}^{2\,WT}$$

Any particular signal which is transmitted for time (T) is one chosen from a total number of M possible signals. The quantity of information is gauged by the number of possible alternatives to a given message, not by the length or number of possible alternatives at any given instant of time. The number (M) is thus a measure of the amount of information in a particular transmission. Following established practice, the unit of information is chosen as the logarithm, to the base 2, of M. One on-off switch has two possible positions; i.e. $\log_2 (2) = 1$; this switch stores one unit of information.

(d) a signal with (M) levels sent in time (T) requires a transmission system capacity (C) equal to

$$C = \frac{\log_2 M}{T} , \quad \frac{\text{units of information}}{\text{second}} .$$

But $\log_2 M = WT \log_2 \frac{P+N}{N}$

or $C = W \log_2 \left(\frac{P+N}{N}\right) = W \log_2 \left(1 + \frac{P}{N}\right)$.

This expresses the speed at which a communication channel can transmit information in terms of bandwidth and the signal to noise ratio.

The impact of this result has been the development of the many systems of modulation such as frequency modulation, pulse-position modulation, and pulse-code modulation. These have the interesting property that it is possible to exchange bandwidth for signal to noise ratio and hence transmit the same information in the same time with less signal power, provided we are willing to use more bandwidth.

Modulation normally can account for the efficient use of a communication channel. From the standpoint of best overall transmission, a form of modulation is preferred which minimizes the probabilities that the signal will be disturbed by extraneous noises

between the transmitter and the receiver. It is possible, by an appropriate modulation process, to trade extra bandwidth for improvement in other system characteristics.

It can be demonstrated that for the maximum rate of communication to be achieved, the message itself, being limited with regard to its power, must be so coded as to have the statistical structure of Gaussian Noise. In this case, the coding is said to achieve maximum entropy in the channel; the information in the message is then perfectly compressed. The practical methods whereby such ideal systems of coding may be achieved still remain to be discovered; however, pulse coding methods approach ideal compression with reasonable effectiveness.

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SUMMARY MEMORANDUM OF CONTACTS

TO: All Who Contributed to this Study

SUBJECT: An Expression of Sincere Thanks for the Cooperation Received

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This study was initiated approximately six months ago. It has been possible only because of the superior cooperation received from everyone contacted and consulted.

As chairman of this study group, I would like to commend the entire technical development staff and the security and operational personnel of the Central Intelligence Agency for their continuous assistance. Without their help in providing technical information and scheduling classified visits to other facilities, this assignment would have been extremely difficult.

Although many groups and individuals gave freely of their time to lend assistance in this effort, the following are mentioned because their contributions have influenced, in no small way, the observations and conclusions that have been set forth. Hopefully, their comments and recommendations have been duly recognized.

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